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SOME EFFECTS OF FREEZING ON ONIONS

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INTRODUCTION

Onions rank as one of the important vegetable crops which are commonly held in storage. Data compiled by the Bureau of Agricultural Economics of the United States Department of Agriculture showing the estimated total production of globe-type onions in the United States and the quantity remaining in storage in the growers' possession and in commercial storage on January 1 for the years 1921 to 1927, inclusive, are given in Table 1.

TABLE 1.—*Estimated production of onions and quantity in storage January 1, 1921–1927*

Items compared	1921	1922	1923	1924	1925	1926	1927
	Carloads	*Carloads*	*Carloads*	*Carloads*	*Carloads*	*Carloads*	*Carloads*
Estimated production	20,168	28,058	28,282	29,948	30,996	31,082	----------
Remaining in growers' hands and in commercial storage Jan. 1	----------	4,010	6,020	7,950	*8,190	8,576	9,065

Two types of onions of outstanding commercial importance are grown in this country—the globe type, of which the Yellow Globe Danvers, Yellow Globe, Prizetaker, White Globe, Silverskin, Red Globe, and Red Wethersfield are well-known representatives, and the Bermuda type, of which the Red Bermuda, White Bermuda, and Crystal Wax are the principal varieties.

The globe onions are commercially grown in the northern areas of the country, where they are harvested late in the summer. After

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being pulled they are dried in the windrow for three or four days. If not sold directly from the field they are cured in slat crates, in open sheds or under tarpaulins, for several weeks or until danger of freezing, when they are placed in storage. By far the larger portion of the stored crop is held in common or dry storage until disposed of, although a certain portion is held in cold storage until late in the season when stock from common storage is exhausted. Common-storage onions are usually marketed by the 1st of March, as it is difficult to keep them in a dormant condition much later because of prevailing high temperatures.

Bermuda onions are grown largely in the South and Southwest. They are usually sold when harvested, although they are held in cold storage to a limited extent.

To study the behavior of onions when exposed to various freezing temperatures a series of experiments was conducted at the cold-storage laboratory at the Arlington Experiment Farm, Rosslyn, Va. The study was confined to northern-grown onions of the globe type, because the larger proportion of this crop is held in common storage in the Northern States and therefore is frequently subject to freezing injury while in storage and in transit to market.

The freezing points and other temperature records were determined by the thermoelectric method, using single-junction copper-constantan thermocouples as described by Taylor.[1] Forty-eight of these couples were installed in one of the experimental freezing rooms and connected with a suspension galvanometer and a potentiometer outside the room, so that after an experiment was once started readings could be made without disturbing the interior of the room. Usually 24 onions with a thermocouple inserted to the center of each were used for each freezing-point determination.

FREEZING POINTS AS INFLUENCED BY STORAGE CONDITIONS

The average freezing point of the globe type of onions is found to be about 30° F., although some variation exists, depending on individual onions and the conditions under which they were grown. That the freezing point varies somewhat with the temperature at which onions have been stored is indicated by the results shown in Table 2, in which are given the freezing points of three different lots for varying periods of time. All figures given represent the average of about 24 separate determinations.

In Table 2 are shown the freezing points of mature Southport Yellow Globe onions grown and cured at South Bend, Ind., by the United States Department of Agriculture. These onions were received at the Arlington laboratory November 14, and after the initial freezing points were determined they were divided and placed in storage at temperatures of 32°, 40°, and 50° F. Subsequent freezing-point determinations were made February 6 and March 21 on lots from the three different storage temperatures, with the results as shown.

In addition there are shown in Table 2 the results of a similar study of the freezing points of a lot of early and late maturing Yellow Globe Danvers onions obtained from the horticultural department of the University of Maryland, College Park, Md., and stored at the Arlington Experiment Farm under conditions similar to those just described.

[1] TAYLOR, G. F. SOME IMPROVEMENTS ON THE NEEDLE TYPE THERMOCOUPLE FOR LOW TEMPERATURE WORK. Jour. Indus. and Engin. Chem. 12: 797–798, illus. 1920.

The early-maturing lot of Yellow Globe Danvers onions were grown under the same conditions as the late-maturing ones; however, they matured about a month earlier. The early-maturing lot was brought to the laboratory August 11 and the late-maturing lot on September 5, on which dates the respective storage tests began.

TABLE 2.—*Average freezing points of mature Southport Yellow Globe onions grown at South Bend, Ind., and of late-maturing and early-maturing Yellow Globe Danvers onions grown at College Park, Md., all stored at Arlington Experiment Farm, Rosslyn, Va.*

Items compared	Southport Yellow Globe, mature			Yellow Globe Danvers				
				Late maturing			Early maturing	
	Nov. 14	Feb. 6	Mar. 21	Sept. 5	Nov. 14	Jan. 4	Aug. 11	Nov. 7
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
When received for storage	29.88			30.18			30.00	
From storage at 32° F		29.73	29.84		29.98	29.90		29.57
From storage at 40° F		29.90	29.99		30.10	30.21		29.97
From storage at 50° F		30.23	30.20		30.20	30.08		30.02

Reviewing these results, there is shown a consistently lower freezing point in onions stored at 32° F. than for those stored at 40° or 50°, although this difference is rather small, apparently indicating that the freezing point of onions is influenced somewhat by temperatures at which they are stored. However, results do not show any consistent change in the freezing points at a given storage temperature in the same lots of onions throughout the storage period.

Since the average freezing point of onions varies around 30° F., this temperature should be considered as a danger point below which the temperature of onion-storage houses should not be allowed to go. A temporary depression below this point may sometimes occur without injury to the onions, because the heat contained within the mass of onions is lost more or less slowly, thus causing a lag between the air temperature of the storage house and the internal temperature of the onions themselves. Illustrating how onions confined in mass, as in a crate, serve as a common protection to one another against freezing, two lots of 1 bushel each, one contained in a standard slat crate and the other spread out on a platform so that the individuals barely touched one another, were subjected to a temperature of 22° without being disturbed. After 24 hours' exposure those that were spread out showed 30 per cent injured by freezing, whereas in the crate lot no injury was apparent. After five days of exposure the crate lot showed 23 per cent injured, and the entire lot spread out was solidly frozen.

UNDERCOOLING AND FREEZING EXPERIMENTS

UNDERCOOLING

Another reason why a temporary depression of temperature below the freezing point may not lead to freezing injury is that onions may undercool or cool below the freezing point without actual freezing taking place. Undercooling in an onion may be terminated at any time and freezing begun by a sudden jarring or by other disturbances.[2]

[2] WRIGHT, R. C. and TAYLOR, G. F. FREEZING INJURY TO POTATOES WHEN UNDERCOOLED. U. S. Dept. Agr. Bul. 916, 15 p., illus. 1921.

Therefore, when onions are known to be cooled below their freezing point they should be handled with care, since a sudden jar, as when crates are roughly handled or onions are poured from crates or bags to be graded, is likely to start freezing in onions which otherwise would warm up without injury. Numerous tests conducted with undercooled onions have never shown injury caused by cooling below the freezing point, provided they were not permitted to freeze.

INDIVIDUAL VARIATIONS AND UNDERCOOLING

There is considerable variation among individual onions relative to the temperature to which they may be undercooled before freezing starts. A typical instance will illustrate how the resistance to freezing varies with individuals. A quantity of selected onions were spread in a single layer on a platform in a room held at about 22° F. and carefully protected from jarring or other disturbances. Lots of 20 were removed at varying intervals beginning at 18 hours and extending through 72 hours. After all lots had been warmed at room temperature for 24 hours the onions were cut and inspected for freezing injury. The lot removed after 18 hours' exposure showed but 10 per cent injured by freezing. Those removed after 24, 42, and 48 hours showed, respectively, 35, 25, and 30 per cent injured. The lot removed after 66 hours showed 75 per cent injury, and the lot removed after 72 hours showed but 45 per cent injured. These results seem to indicate that under the conditions of the experiment there was little correlation between the duration of exposure and the amount of injury found. The explanation possibly lies in the wide variation found in onions which allows certain individuals to remain undercooled for a comparatively long period.

Figure 1 illustrates the temperature change as measured by a thermocouple in each of two onions. These onions were located among a number of others spread out so as not to touch one another and allowed to remain undisturbed at a temperature of 19° F. One reached a temperature of 25.2° 30 minutes after the beginning of the experiment, and freezing then commenced, the temperature rising to the freezing point and remaining there until the onion was frozen solid. The other onion did not begin to freeze before 105 minutes, reaching a temperature of 20.2° before freezing commenced.

RESISTANCE TO FREEZING

Several tests were conducted to study the resistance of onions to actual freezing when subjected to temperatures below the freezing point. In one of these tests eight 4-quart baskets containing 20 onions each were placed in a room at 27° F., a temperature which is not far below the freezing point. On the second and each succeeding day to and including the ninth, a basket was removed from the freezing room to a temperature of about 70° F. Subsequent inspection showed freezing injury to be present only in the basket removed on the ninth day. In this lot three specimens showed slight injury. Although these onions were held at a temperature below their freezing point, apparently it was not low enough to cause serious freezing within the time limit of the experiment. All those not frozen undoubtedly remained undercooled most of the time the experiment was in progress.

FREEZING INJURY IN A YELLOW GLOBE ONION

The entire outer scale is injured; the next one uninjured; the third and fourth ones are injured, while the center is uninjured

The results of another experiment are illustrated in Figure 2. A standard slat crate containing a bushel of onions was transferred from 32° F. storage to a temperature averaging about 21°. Thermocouples were inserted in two onions centrally located in the crate near the top, in two directly beneath them near the bottom, and in two as nearly at the center of the crate as possible. Because the temperatures at the center of the crate were so nearly the same as those at the top they are not shown. For the first 24 hours temperature readings were made practically every two hours. The most rapid fall occurred near the bottom of the crate during the first 12 hours, after which the curves flattened out. The probable freezing point (30°) was passed in the first hour of the experiment, following which the onions remained undercooled for at least 47 hours, reaching a recorded minimum temperature of 24.1° and 24.7°, respectively. By this time the rate of fall had so greatly diminished that it is not probable that the temperature fell much below this minimum between recording intervals. Some time after the forty-seventh hour freezing commenced, as when the next records were made on the seventieth hour the temperatures had risen to 25.7° and 28.5°, indicating that freezing was in progress. Apparently the freezing point was reached before the records made on the seventieth hour, and the temperatures taken at this time were approaching that of the surrounding air, as the freezing was almost complete. Near the top of the crate the probable freezing point was not passed until about the third hour, and the rate of fall was slower than at the bottom. Some time after the seventieth hour, when both onions had reached an undercooled temperature of 25.7°, one evidently commenced to freeze, as the next temperature recorded was 30.4°, the probable freezing point, after which the tempeature rapidly lowered. The other onion apparently did not freeze, but remained undercooled throughout this test, reaching a recorded minimum of 25.1° in 118 hours. Examination of the rest of the onions in the crate at the completion of the experiment showed less than 5 per cent to have been injured by freezing.

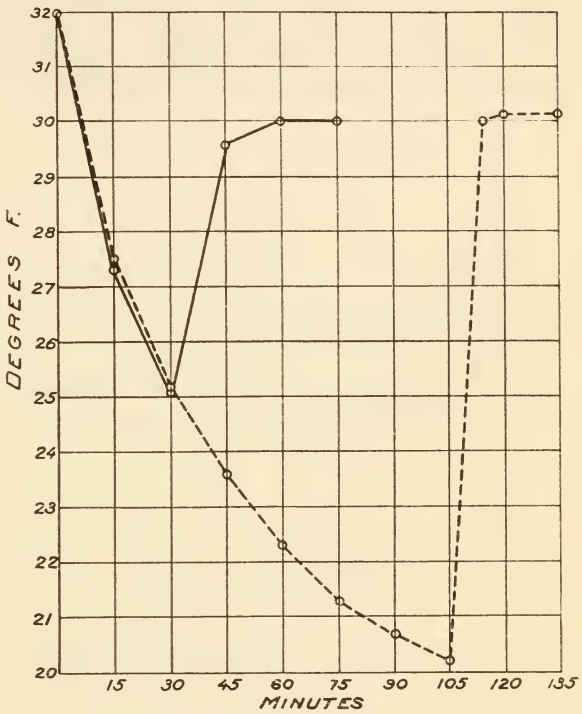

FIG. 1. —Individual variation in the undercooling of two representative onions

Another experiment was conducted to study the length of time that a bushel slat crate of onions could be held at low temperatures without injury. Twelve crates taken from the regular 32° F. storage were placed at 22°. Duplicate crates were taken out in 2, 4, and 6 days thereafter and held at 40° until inspected. Six days after the last crates were removed inspections were made by cutting 50 specimens from each lot. The onions with 2 days' exposure at 22° showed no injury, but in the crates removed after 4 days 15 per cent of the onions were frost injured, as evidenced by the characteristic transparent areas in the scales. In the lots removed after 6 days 25 per cent proved to be injured. In addition it is important to note that after 6 days' exposure the frozen onions were injured all the way through, whereas those found frozen in the crate after 4 days' exposure were injured only around the outer layer of scales.

In another somewhat similar experiment, thermocouples were placed in 12 onions scattered throughout a filled crate held at a

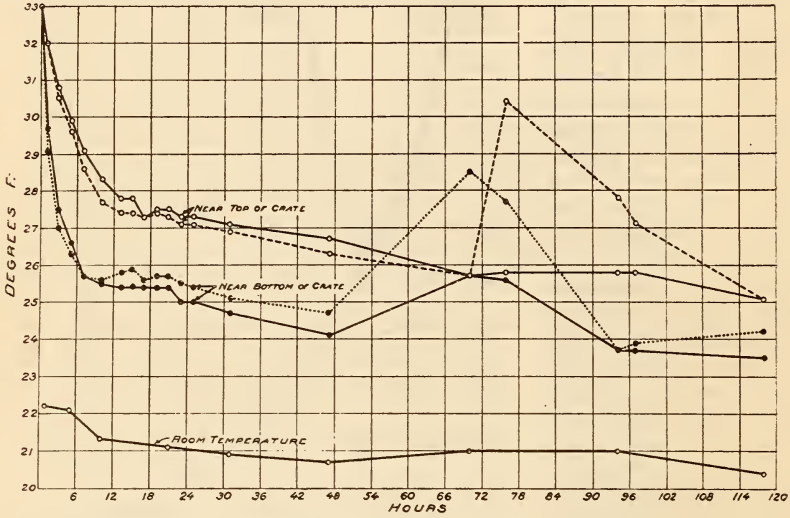

FIG. 2.—Rate of cooling and undercooling of onions near the top and bottom in a standard slat crate containing 1 bushel

temperature of 22° F., to determine the time that these onions would remain undercooled in a commercial container. The test extended for 13 days, when 10 of the onions had frozen, leaving 2 still undercooled. After the onions had been allowed to warm up for 2 days an inspection showed that 68 per cent of the entire lot were injured.

EXTENT OF FREEZING INJURY AS AFFECTED BY SUBSEQUENT STORAGE TEMPERATURES

It has been repeatedly noticed that when onions which had been allowed to freeze were transferred to a temperature around 31° or 32° F., the extent of freezing injury was greater than when they were removed immediately to a higher temperature.

In one experiment, after onions had been exposed to a freezing temperature of 22° F. for 6 days, the lot was divided and a portion stored at 40° and another at 32° for a week. On inspection it was found that of the onions stored at 40° only 25 per cent showed freezing injury, none of which was extensive, whereas 75 per cent of those

stored at 32° showed severe injury, due possibly to the fact that ice was still present in the tissues.

In another test a bushel of onions were spread out so that they scarcely touched one another and were held at a temperature of about 20° F. for 24 hours. These onions were then removed and a part held at 50° and a part at 32° for three days, uniform care being observed in handling both lots. Inspection revealed that 65 per cent of those held at 50° showed slight freezing injury near the surface, whereas at 32° 91 per cent were badly frozen almost to the center, with considerable ice still present. It seems reasonable to suppose that the greater injury found at 32° may have been due to the onions actually remaining below their freezing point for a long period of time before being warmed up sufficiently to stop freezing action, or to the presence of ice within the tissues for a much longer time.

FREEZING INJURY AS AFFECTED BY HANDLING WHEN UNDERCOOLED

The statement that when onions are undercooled this condition may be terminated at any time by sudden jarring is illustrated in the following experiments. A bushel lot of selected specimens from the regular 32° F. storage was spread out into a single layer in a room held at 22° and left undisturbed for six hours. Part of the onions were then tossed into a basket and spread out again. In 24 hours all the onions were removed to a warm room. Two days later an inspection showed freezing injury in 80 per cent of those that were tossed into the basket and no injury present in those left undisturbed.

In another experiment a bushel of onions were spread out and left at 26° F. for six days, when a part of them were tossed into a basket and again spread out. After two days more at the same temperature all were removed to a warm room. An inspection of the lot that was disturbed showed 53 per cent to be injured, whereas in the undisturbed lot 29 per cent were injured. The period of exposure in this experiment was apparently too long for some of the individuals to withstand freezing even when undisturbed.

A test in which commercial conditions were simulated was conducted by leaving two 100-pound bags of onions in an outdoor shed overnight when the minimum temperature reached 20° F. The following morning one bag was loaded on a farm wagon and hauled about for 45 minutes. Subsequent inspection after both bags were warmed up showed that 25 per cent of the onions in the bag that was hauled were injured, as compared with 7 per cent in the undisturbed bag.

RELATION OF APPARENT FREEZING INJURY TO DURATION OF FREEZING EXPOSURE

In an experiment to determine how soon freezing injury becomes apparent after actual freezing occurs, 50 representative specimens with thermocouples inserted to the center of each were spread out in isolated positions in a freezing room held at 22° F. As they reached an undercooled temperature of between 25° and 26° they were inoculated by quickly withdrawing and inserting the thermocouple two or three times. The temperature of the onions was watched carefully, and the time of the inception of freezing in each individual, as marked by the rapid rise in temperature from the undercooled temperature to the freezing point, was noted. Lots of 10 specimens each were plunged into warm water to stop immediately the progress of freezing, one-half hour, 1, 2, 3, and 4 hours after freezing commenced. Subsequent

inspection showed no apparent injury in the onions which were allowed to freeze one-half hour and 1 hour. After 2 hours 30 per cent of the onions showed injury, and after 3 and 4 hours 70 per cent were injured. These experiments indicate that onions are not so readily injured by freezing as are some other products. Investigations in this laboratory have shown potatoes, for instance, to be injured in as short a period as one-half minute after actual freezing commences.[3]

FREEZING INJURY

Injury caused by freezing is usually determined by cutting specimens either longitudinally or transversely. The affected tissue appears to be water-soaked, discolored, and more or less transparent with indefinite scattered opaque areas. Symptoms of freezing injury are frequently and easily confused with those of physiological breakdown caused by excessive heat and other undetermined factors. When cut, such affected specimens show certain transparent discolored scales similar to those caused by freezing injury, but usually without the scattered opaque areas. Freezing usually includes an entire scale all or nearly all the way around the onion. Often one scale is found injured while the adjoining ones may be normal. Following light freezing, usually the outer scale only is affected; with more severe freezing the injury is found in the more inner scales, often skipping one or two scales as it penetrates toward the center. The last portion to succumb is the heart or growing point, at the center of the base or receptacle, as illustrated in Plate 1. Determinations made in 12 specimens at the center near the top and at the center at the base show the freezing point to be somewhat lower at the latter than near the top. The average freezing point at the base or root end is 29.95° F., and that at the top is 29.5°. Lightly frozen onions (those with only the outermost scales frozen) can usually be saved from severe loss if handled so they can be thoroughly dried out. The water-soaked scales dry out and leave the onions somewhat softer than before freezing, but otherwise in good condition. On the other hand, if they are left in a damp storage or with insufficient ventilation, such injured onions will soon start to decay.

SUMMARY

The average freezing point of onions of the globe type is about 30° F.

The freezing point varies somewhat with the temperature at which onions are held in storage.

Onions may undercool below their freezing points without freezing; thus freezing does not always follow exposure to low temperature.

Onions should not be moved or handled roughly when cooled to temperatures below their freezing points, for if undercooled and so handled they are likely to freeze immediately.

Freezing injury is easily confused with the results of physiological breakdown brought about by various causes.

Onions with only the outermost scales injured by freezing may, as a rule, be salvaged if allowed to dry out.

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[3] WRIGHT, R. C. LOW TEMPERATURE INJURY TO POTATOES IN STORAGE. Potato Assoc. Amer. Proc. Ann. Meet. (1924) 11: 54–59. [1925]

——— FREEZING INJURY TO POTATOES IN STORAGE OR TRANSIT. Amer. Assoc. Ice and Refrig. Proc. Ann. Meet. (1924/25) 14: 119–123, illus. 1925.